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Design of quantum dot semiconductor optical amplifier by intelligence methods

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Abstract

The outstanding features of Quantum Dot Semiconductor Optical Amplifiers (QD-SOA's) such as all-optical signal processing and signal regeneration are caused them are widely used in the optical communication systems. Due to the nano structure of these amplifiers, accurate design and modelling of them is a complex and challenging problem. This paper addresses design a QD-SOA. We present a novel method based on genetic algorithm to design QD-SOA. Since it is essential to having a model for designing, a numerical model is obtained in the first step. Then, an artificial neural network model is made using training data sampled from numerical model. The experiments show the proposed neural model has high accuracy as well as low computation time. In the next step, we convert the design problem to a genetic algorithm problem. Using neural model, the suitable fitness function is defined. The user can optimize the cost of production by setting the weight for the design parameters. The proposed system finds the best solution that satisfies desired gain regarding the production cost.

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1. Introduction

Nowadays, Quantum Dot Semiconductor Optical Amplifiers (QD-SOA's) are used for amplification and all-optical signal processing at the high speed in fiber-optic communication networks. A QD-SOA contains a nano-structured layer which has a quantum mechanical interaction with light [1]-[2].

Theory of optical signal amplification and processing by quantum-dot semiconductor optical amplifiers (SOA's) is based on the density matrix equations to treat electron-light interaction and the optical pulse propagation [3]. This object causes the complicated design for QD-SOA. Therefore, it can be very useful to introduce the optimal design for this amplifier by intelligence methods. Genetic algorithm (GA) determines the optimal amounts of model inputs considering desired gain. For this design, it is essential to have an artificial neural network (ANN) model and numerical data. In this paper, a QD-SOA with demanded gain is designed. Any paper isn't reported in optimal design of QD-SOA, yet.

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This paper is organized as follows: The ANN model for QD-SOA is presented in Section 2. In Section 3, Optimal design by Genetic Algorithm is presented. Finally, Section 4 contains the conclusion.

2. QD SOA ANN MODEL

An Artificial neural network learns general rules based on calculation upon numerical data. Smallest part of ANN is neuron. In figure 1, Schematic of a neuron is shown. It receives input from some other neurons, or perhaps from an external source. Each input, x has an associated weight w, which can be modified so as to model learning. The neuron computes some function f of the weighted sum of its inputs:

$$y = f(\sum w.x + b) \tag{1}$$

f is transfer function. One of the common transfer functions is a sigmoid function which is a mathematical function that are often used in neural networks to introduce nonlinearity in the model and/or to make sure that certain signals remain within a specified range. Sigmoid function is defined by the formula :

$$y = 1/_{1+e^{-t}} \tag{2}$$

The most common structure of ANN is the multilayer Feed Forward Network. In Feed Forward NNs, the neurons are organized in the form of layers. The neurons in a layer get input from the previous layer and feed their output to the next layer. In this kind of networks connections to the neurons in the same or previous layers are not permitted. The last layer of neurons is called the output layer and the layers between the input and output layers are called the hidden layers. The input layer is made up of special input neurons, transmitting only the applied external input to their outputs.

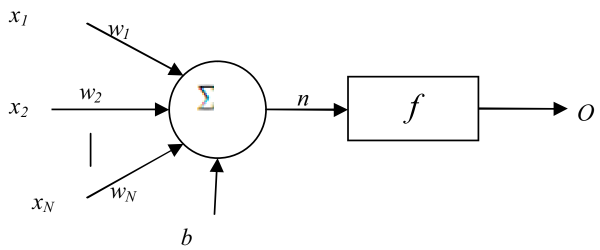

Fig. 1. Schematic of a neuron

In a network if there are only one or more hidden layers, such networks are called multilayer networks. The back-propagation algorithm has emerged as the workhorse for the design of a special class of layered Feed Forward Networks known as Multilayer Perceptrons.

At the first step, we have gathered data of InAs/GaAs QD-SOA in the 1.3-µm wavelength. For this purpose, modelling by numerical methods is achieved for the mentioned QD-SOA. For The details of this numerical model of QD-SOA is referred to [4]. An artificial neural network model is presented. After several try and tendency toward a simpler model, the type of ANN is chosen a Feedforward NN with one hidden layer, four inputs and one output. The inputs of this ANN model are the length of device, effective thickness of active medium, applied current density, and confinement factor and the output is amplifier gain. The used Algorithm in this model is Back Propagation Algorithm because mentioned algorithm don't need the quite accurate data .The obtained data is divided to 3 parts: training data, Check data, and test data. The ANN model is trained by training data. The check data is used to prevent overfiting problem. The test data is used to evaluate ANN model. The transfer function in hidden and output layers is Sigmoid and Pure line function, respectively.

We trained the Feed Forward ANN models with different neurons in hidden layer. The performance Index is Mean

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Square Error. Because of non-optimum responses and convergence to local minimum, ANN is trained for several times and training data isn't disposed regularly. In this condition, we obtained the best responses. In tables 1,some of the results of training ANN are shown.

Table 1. Results for nondespersal training data and different neurons

Network Structure	Training Errors	Testing Errors	Epoch(#)
4:3:1	0.768	0.994	21
4:5:1	0.137	0.216	62
4:7:1	0.024	0.024	49
4:11:1	0.0007	0.003	141
4:13:1	0.0004	0.0051	21
4:16:1	0.00059	0.00333	109
4:17:1	0.00014	0.00066	134

As it is seen, the best result has been obtained for ANN with 17 neurons in hidden layer. In this model, Mean Square Error for test data is less than 0.0007 that shows high accuracy of model.

3. Optimal Design by Genetic Algorithm

GAs are optimization algorithms based on Darwinian theory. they operate on a coded version of the design parameters, instead of directly on these parameters themselves.Basically, a genetic algorithm selects design parameter as "parents," forming "offspring" by recombining components from the parent parameter. The offspring displace weak parameters in the system and enter into competition, being activated and tested when their conditions are satisfied [5]. Thus, a genetic algorithm crudely, but at high speed, mimics the genetic processes underlying evolution.

In this research, the purpose is design of the amplifier with desired gain. For attaining the purpose, optimizing the effective parameters considering to desired gain is required. It means that effective parameters are optimized whereas it is attained desired gain by minimum cost. This approach used genetic algorithm.

After modelling and definition of proper ANN structure for optimization of parameters, the approach is to attain the desired gain by GA toolbox of MATLAB Software. At first, the variables of problem and Fitness Function are defined. The variables of problem are the same of the inputs of ANN model. Fitness Function is given:

$$y = v.h + cf(x) \tag{3}$$

As shown, Fitness Function contains of two terms. The first term is related to algorithm error, where h is given:

$$h = hard\lim(e) \tag{4}$$

And

$$e = G_{Actual} - G_{Desired} \tag{5}$$

Where G_{Actual} is actual gain and $G_{Desired}$ is desired gain which is obtained from the proper ANN model. The second term is related to effective parameters, is called Cost Function. Cost Function is given:

$$cf(x) = \sum_{i=1}^{4} w_i . x_i \tag{6}$$

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Where x_i is the variables of algorithm (4 input parameters in ANN modelling) and w_i is related weight for variables. w_i depend on conditions of Maker Company. It means that the variable with more importance (with more cost) has a more weight. In Fitness Function, if actual gain is more than desired gain, the first term is omitted and just cost function become importance. The value of first and second term of Fitness Function is defined by choosing proper value for v.

In this research, actual gain is attained for ANN with 17 neuron and experiments is done for defining optimization effective parameter by GA toolbox in MATLAB Software. At first, by sequential experiments, the best Fitness Function and the value of v obtain. Optimal design is achieved, when roulette wheel is the selection function and first population and crossover is 40 and 0.8, respectively, and in the best condition, value of v is between 100 to 400. Then, for different weight, the experiments are repeated. The results of these experiments are shown in table 2.

Table 2. Results for design of QD-SOA by GA

Weight	V	$G_{Desired}$	G_{Actual}	cost
[5 1 2 5]	250	17	17	46.23
[5 1 2 5]	400	17	17.11	48.32
[1 2 5 5]	250	17	17	54.51
[1 2 5 5]	400	17	17	57.23
[5 2 1 5]	250	17	17.03	51.31
[5 2 1 5]	400	17	17.19	50.35
[5 5 1 2]	250	17	17	61.66
[5 5 1 2]	400	17	17	57.12

According to the experiments, when the value of v is 250 and the weight is [5 1 2 5], the best fitness is attained. Generally, GA has a proper potential to finding optimal value of effective parameters in QD-SOA considering desired gain.

4. Conclusion

In this work, a new approach to determine the optimal amounts of model inputs considering desired gain is presented. This approach used genetic algorithm. According to the experiment by GA, the best selection function, crossover and first population for the optimal design are determined and appreciate v for the best fitness function is attained. Generally, the proposed approaches give suitable results in term of material cost considering desired gain.

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